DEC STD 120-0 Product Thermal Design Standard: Design Requirements

DOCUMENT IDENTIFIER: A-DS-EL00120-00-0000 Rev B1, 28-Feb-1990

ABSTRACT: This standard establishes the minimum thermal requirements for acceptable Digital products and defines the responsibilities and procedures required to design products to meet these requirements.

APPLICABILITY: Mandatory for use by Digital personnel responsible for the thermal aspects of the design, development, and manufacture of Digital products worldwide. This includes buy-out products.

STATUS: APPROVED 28-Feb-1990; use VTX SMC for current status.

This document is confidential and proprietary, and is the property of Digital Equipment Corporation. It is an unpublished work protected under the Federal copyright laws.

©Digital Equipment Corporation. 1990. All rights reserved.

DEC STD 120-0 Product Thermal Design Standard: Design Requirements

DOCUMENT IDENTIFIER: A-DS-EL00120-00-0000 Rev B1, 28-Feb-1990

REVISION HISTORY:	Rev A,	06-Mar-1975	
	Rev B,	13-Feb-1989	ECO Number CT001
	Rev B1,	28-Feb-1990	ECO Number CTS02
Document Management Category:	Thermal Design (HPT)		
Responsible Department:	Mechanical Technology Development (MTD)		
Responsible Person:	Ralph Larson		

APPROVAL: This document has been recommended for use throughout Digital by the General Review group for its category. Rev B1 incorporates clerical changes only.

Ralph Larson - Mechanical Technology Development

Eric Williams - Standards Process Manager

Direct requests for further information to:

Ralph Larson
Use $ VTX ELF for the latest location information

Use VTX SMC to order copies of this document from Standards and Methods Control. Send distribution questions to JOKUR::SMC or call DTN: 234-4423.

CONTENTS

1 INTRODUCTION 1
1.1 PURPOSE 1
1.2 SCOPE 1
1.3 SUMMARY 1

2 RESPONSIBILITIES 2
2.1 THERMAL ENGINEERING GROUP (TEG) 2
2.1.1 Summary of Responsibilities 2
2.1.2 Consulting Services 2
2.2 RESPONSIBLE ENGINEER 2
2.2.1 Summary of Responsibilities 2
2.2.2 Waiver 3
2.3 PRODUCT BUSINESS UNITS, SYSTEMS PROGRAM OFFICES, AND FIELD ORGANIZATION 3

3 DEFINITIONS 3

4 THERMAL DESIGN REQUIREMENTS 4
4.1 GENERAL 5
4.2 ENGINEERING DESIGN SPECIFICATION/PURCHASE SPECIFICATION 5
4.2.1 Thermal Design Requirements Data 5
4.3 DESIGN THERMAL ENVIRONMENT CLASSIFICATION 6
4.3.1 Stand-Alone Products 6
4.3.2 Embedded Products with Coolant Flow Device 7
4.3.3 Embedded Products without Coolant Flow Device 7
4.4 STANDARD DESIGN CONDITIONS 7
4.4.1 Cleanliness 8
4.4.2 Thermal Surroundings 8
4.4.3 Flow Paths 9
4.4.4 Altitude Correction 9
4.5 THERMAL DESIGN DATA FOR EMBEDDED PRODUCTS 9
4.6 THERMAL OPERATING CONTROLS 9
4.7 THERMAL LIMIT CONTROLS 9
4.8 THERMAL - ACOUSTIC INTERACTION 10
4.9 SUBSYSTEM THERMAL DESIGN DATA 10

5 THERMAL DESIGN VERIFICATION TEST 10
5.1 GENERAL 10
5.2 PURPOSE 10
5.3 TESTING LOCATION 10
5.3.1 Test Environment 11
5.3.2 Test Conditions 12

5.4 COMPUTATION OF EXPECTED TEMPERATURES 12
5.4.1 Corrections to/for Maximum Environment Temperature 13
5.4.2 Correction to Limit Location 13
5.4.3 Correction for Maximum Component Heat Output 13
5.4.4 Example of Computations and Corrections 14
5.5 COMPUTATION OF MAXIMUM OPERATING TEMPERATURE RANGE 15
5.6 REPORT 16
5.7 PASS/CONDITIONAL PASS/FAIL CRITERIA 16
5.8 FAILED THERMAL DESIGN VERIFICATION TEST REQUIREMENTS 17

6 COMPONENT THERMAL LIMITS 17
6.1 MAXIMUM TEMPERATURE LIMITS 17
6.2 DESIGN TEMPERATURE LIMITS 18
6.2.1 Design Temperature Limits Using Guidelines 18
6.2.2 Design Temperature Limits from Temperature Versus Reliability Data 18
6.2.3 Design Temperature Limits from Maximum Temperature Limits 18
6.3 DESIGN TEMPERATURE RANGE LIMITS 19
6.4 RATE OF CHANGE OF TEMPERATURE LIMIT 19

7 THERMAL DESIGN PRACTICES 19
7.1 THERMAL DESIGN STRATEGY 20
7.1.1 Component Heat Output 20
7.1.2 Thermal Related Reliability 21
7.2 ANALYSIS AND EXPERIMENTATION 21
7.3 DOCUMENTATION OF PRODUCT THERMAL DATA 21
7.4 PURCHASING OR ENGINEERING SPECIFICATION DATA FORMAT 23
7.4.1 Data Format 23
7.4.2 Coordination 25
7.5 MANAGEMENT CHECKLIST 25

Appendix A REFERENCED DOCUMENTS 27

A.1 EL-Class Digital Documents 27

1 INTRODUCTION

This standard takes precedence over all other Digital standards and specifications as related to minimum thermal design standards.

1.1 PURPOSE

The ultimate goal of this standard is to ensure that Digital products are engineered and manufactured in compliance with a set of minimum thermal design requirements.

The purpose of these requirements is to ensure that all powered equipment sold by Digital are competitive and reliable, insofar as these qualities are affected by component operating temperature.

It is a further purpose of this standard to establish a central repository for product thermal data, including product thermal design requirements and product thermal design verification test results. This will provide the thermal design community ready access to product and component thermal data (temperature limits, thermal resistances, and so on) and, thus, contribute to increased productivity and reduced design cycle time.

1.2 SCOPE

This standard applies to all powered products sold by Digital.

This standard complements *DEC STD 102-0 Environmental Standard for Computers and Peripherals - General Test Requirements* in that it uses the product environmental classifications set forth in DEC STD 102-0, where applicable. This standard is different from DEC STD 102-0 in that this document provides guidance, structure, and consistency for the thermal design process, so the product is intentionally designed to meet, as a minimum, the environmental limits required by DEC STD 102-0.

1.3 SUMMARY

This standard requires that minimum thermal requirements for a powered product be defined and documented; describes practices and procedures for setting and meeting those requirements; and defines a test procedure for verifying that thermal requirements have been met. The major provisions and objectives of this standard are to:

- Identify the thermal design requirements for the product under design early in the design cycle. This includes the establishment of measurable thermal limits for all components used in the design.
- Provide guidance in the application of thermal design engineering principles to achieve an acceptable thermal design.
- Acknowledge the relationship between thermal design, acoustics, and reliability in the design process.
- Present a straightforward and consistent method of experimentally verifying that the design meets the thermal limits to which the product was designed.
- Establish the Thermal Engineering Group as the central repository for product thermal design requirements and thermal design verification test results.

- Clearly define the responsibility of the responsible engineer, as named in the Option/Module Hardware list, to ensure that the provisions of this standard are met.

2 RESPONSIBILITIES

2.1 THERMAL ENGINEERING GROUP (TEG)

2.1.1 Summary of Responsibilities

The Thermal Engineering Group is responsible for:

- Maintaining this standard and assisting users in its interpretation and use
- Periodically reviewing this standard to ensure its appropriateness and completeness
- Retaining and archiving all final reports and test records pertaining to thermal performance in compliance with this standard
- Random monitoring of reports and test records of applicable hardware products by review of retained reports, verification of test results, or any other means

2.1.2 Consulting Services

In a consulting role, TEG provides the following services:

- Contracted thermal design engineering assistance and support to product development teams.

  In the contracted thermal design engineering role, the preferred procedure is to assign a TEG engineer to work as a part of the development team from the design inception phase onward. In such cases, some of the responsibilities defined under subhead 2.2 may be delegated (by mutual agreement) to TEG. If packaging concepts at the conceptual and mock-up stage are thermally sound, and attention to thermal design features is continued throughout the remainder of the design, the final product is likely to meet thermal requirements.
- Thermal design verification testing or test assistance near the completion of product development and early in manufacture.

2.2 RESPONSIBLE ENGINEER

2.2.1 Summary of Responsibilities

The responsible engineer, as named in the Option/Module Hardware List, is responsible for ensuring that:

- The product thermal design requirements are defined and documented in accordance with the requirements contained under subhead 4.2.
- The product is designed to meet these requirements.
- The product is subjected to thermal design verification testing. Refer to heading 5.
- The product can be exercised with appropriate diagnostic routines or operational tasks for verification testing.
- A copy of all final reports and test results documenting thermal design and performance are submitted to TEG in a timely manner.

- Design modifications and/or component changes implemented subsequent to successful completion of the thermal design verification testing do not adversely affect or impact the thermal design of the product or negatively influence the outcome of the thermal design verification test, if repeated.

2.2.2 Waiver

If it is necessary that the product design conditions or testing procedure deviate from the requirements of this standard, the responsible engineer is responsible for obtaining a waiver in accordance with the requirements defined in *DEC STD 066-2 Waivers to Digital Design Standards*.

2.3 PRODUCT BUSINESS UNITS, SYSTEMS PROGRAM OFFICES, AND FIELD ORGANIZATION

It is the responsibility of individual product business units (PBUs), systems program offices, and the field organization to ensure that the stated goals of the product are consistent with marketing intentions. This specifically includes a review of the Design Thermal Environment Classification to ensure appropriateness. The Design Thermal Limits and Thermal Environment Classification will be made visible through the phase 0 product plan and the design review process.

3 DEFINITIONS

Cooling mode - The method or methods by which components are cooled: natural convection, forced convection, conduction, and radiation.

Design temperature limit - The highest temperature allowed for a component of a product operating under standard design conditions. This temperature refers to a temperature at a specific location on or in the item.

Design thermal environment classification - The thermal conditions in which a product must operate. That is, the maximum ambient or local ambient temperature, the maximum variation in ambient or local ambient temperature, and the maximum rate of change of ambient or local ambient temperature.

Expected temperature - The estimated maximum in-service temperature of a component, unit, or subassembly obtained by correcting measured temperature data for the test ambient temperature, measurement position, and in some cases, power. Refer to subhead 5.4.

Fully configured product - A product that has all optional modules and subsystems installed.

Heat output - Net energy per unit time leaving a device, component, subsystem, or system as thermal energy.

Maximum junction temperature - The expected operating temperature of a device die or chip, usually expressed in degrees Celsius.

Maximum operating temperature condition - That normal operating condition that will result in the maximum attainable temperature on any device or component within an operating system.

Maximum temperature limit - The highest operating temperature at which a component is warranteed by its manufacturer. This temperature refers to a temperature at a specific location on or in the item.

Product environment classification - Classifications set out in *DEC STD 102-1 Environmental Standard for Computers and Peripherals - Temperature, Humidity, and Altitude Requirements* that define classes of operating environments for Digital products based on temperature and humidity.

Steady state condition - Theoretically, this is constant temperature over time, but more practically, it means *fully warmed up*. Small oscillations in temperature are tolerated as long as the average is constant. This generally applies to both the equipment and the environment of the equipment.

Thermal design engineering - Analytical and experimental techniques applied to temperature control problems. In this case, the cooling of computers, peripherals, subassemblies, and components.

Thermal limit control - An automatic power shut-off used to prevent the maximum temperature limit of any component from being exceeded when the product is subjected to a blockage, fan failure, or other upset condition during operation.

Thermal operating control - A cooling system with a controller that senses the temperature and adjusts accordingly. This could include a shutdown procedure for thermal overload conditions.

Thermal resistance, case-to-ambient - A measured or calculated value indicating the resistance to heat flow, typically in units of degrees Celsius per watt (C/W), from a referenced point on a device case or package to the local ambient or the surrounding air. For both forced and natural convection cooled systems, the surrounding or local air temperature is meant to be the temperature of the bulk air outside the boundary layer that occurs immediately adjacent to the device in question.

Thermal resistance, junction-to-case - A measured or calculated value indicating the resistance to heat flow, typically in units of degrees Celsius per watt (C/W), from a device die or chip to a specified external point on the device enclosure or case.

Upset condition - The state when unusual external conditions impede the effective operation of a unit's cooling system.

Velocity - The flow rate of a gas or liquid past a particular reference point, typically measured in units of length per unit of time.

Volumetric coolant flow rate - The volume of coolant, typically air, flowing through a product per unit of time.

4 THERMAL DESIGN REQUIREMENTS

All powered products sold by Digital shall meet the thermal design requirements that follow.

These requirements apply to stand-alone products, as well as to components, modules, drives, embedded products, and so on, that are used or intended for use as part of stand-alone products.

4.1 GENERAL

Any powered product sold by Digital shall be designed so that all components, units, or subassemblies comprising the product will operate at or within their Design Thermal Limits when the product is operated to the extremes of its Design Thermal Environment Classification.

4.2 ENGINEERING DESIGN SPECIFICATION/PURCHASE SPECIFICATION

For powered products designed by Digital, the product engineering design specification prepared for the Concept Review step in the Design Review Process shall contain a section entitled *Thermal Design Requirements* that shall include, as a minimum, provision for the data listed under subhead 4.2.1.

For powered products designed or manufactured externally and purchased by Digital for use in, or for resale as, Digital products, the data listed under subhead 4.2.1 as a minimum, shall be included in the purchase specification.

4.2.1 Thermal Design Requirements Data

- A description of the thermal control approach including modes of cooling and significant thermal design features.
- Specific acceptance criteria.
- The Design Thermal Environment Classification. Refer to subhead 4.3.
- Design and maximum temperature limits for components, subassemblies, and units comprising the product. Refer to heading 6.
- Design temperature range limits for components, subassemblies, and units where temperature range limits are applicable.
- Rate of temperature change limits for components, subassemblies, and units where rate of change limits are applicable.
- Steady state heat output values for all modules and subassemblies comprising the product (average and maximum values are required). Heat output values for critical components (average and maximum values) will also be supplied as required.

  In general, this data is to be supplied at the average electrical supply conditions. It is recognized that heat output is a function of supply voltage. In instances where component temperatures are approaching their design thermal limits, heat output values should also be supplied at the minimum and maximum conditions.
- A description of the various option combinations at which the product can be configured. This shall include, if possible, identification of configurations that represent the worst case thermal conditions for components, modules, or subassemblies.
- A description of various operating modes for the product insofar as operating mode affects heat output.
- Thermal design data per subhead 4.9, if required.
- Clearance required around the exterior of the product enclosure to ensure that air flow paths are not restricted.
- Design altitude range during operation.

- Thermal operating control, if applicable.
- Thermal limit control, if applicable.
- Product reliability requirements, as well as the reliability parameters of all critical components or those components comprising 80% of the overall reliability budget. Refer to *DEC STD 009-2 Product Engineering Specifications: Requirements for Specifying Reliability Parameters*.
- Design duty cycle(s).
- Environmental air quality (if not normal office air), including information on the type and loading of any contaminants.
- Air quality required for direct cooling of the product and/or any subsystems or components, if different from the environment air quality.
- Special thermal requirements not covered above.

For products designed by Digital, this data set is to begin at the inception of a product design project. This data set shall be updated and expanded as the design process continues and the product is further defined and is to be completed prior to thermal verification tests required per heading 5.

For products designed or manufactured externally and purchased for use in, or resale as, Digital products, this data is to be completed with the vendor either during purchase negotiations or, at the latest, prior to the thermal design verification test, as required per heading 5.

The above data set is for internal design purposes only and is not to be included in the product engineering specification as defined in *DEC STD 009-1 Product Engineering Specifications: Electrical, Physical, and Environmental Parameters*. The data required above is distinct from that required by DEC STD 009-1. The data required by this standard documents the basis for the thermal design while that required by DEC STD 009-1 is a compilation of thermal data that is of use to the customer or field service personnel.

The specific data used for design purposes is considered proprietary and, as such, may only be released to customers or published in accordance with Digital's policy on proprietary data.

4.3 DESIGN THERMAL ENVIRONMENT CLASSIFICATION

All powered products sold by Digital shall have a Design Thermal Environment Classification that specifies the thermal conditions in which the product must operate.

4.3.1 Stand-Alone Products

For stand-alone products or separately mounted products, the thermal environment classification shall specify the worst case operating environment in which the product is expected to operate and meet the product reliability requirements as defined in DEC STD 009-2.

This classification shall be consistent with the environmental classifications in DEC STD 102-1 if such a classification is applicable, and shall specify:

- Maximum environment temperature

- Minimum environment temperature
- Maximum environment temperature range
- Maximum rate of environment temperature change

4.3.2 Embedded Products with Coolant Flow Device

For products that may be embedded within other Digital products, and that incorporate cooling means, such as an air moving device, the Design Thermal Environment Classification shall specify:

- Maximum local environment temperature at the location where the coolant enters the embedded product
- Minimum local environment temperature at the location where the coolant enters the embedded product
- Maximum local environment temperature range
- Maximum rate of change of the local environment temperature
- Maximum, externally imposed, flow resistance against which the coolant flow device can operate and appropriately cool the embedded product

4.3.3 Embedded Products without Coolant Flow Device

For products that can be incorporated into and used as part of a number of Digital products, and that do not include a coolant flow device, such as a fan or blower, the Design Thermal Environment Classification shall specify:

- Maximum local environment temperature at the location where the coolant enters the embedded product
- Minimum local environment temperature at the location where the coolant enters the embedded product
- Maximum local environment temperature range
- Maximum rate of change of local environment temperature
- Required coolant flow velocity at the maximum local environment temperature, if applicable
- Required volumetric coolant flow rate at the maximum local environment temperature, if applicable

4.4 STANDARD DESIGN CONDITIONS

Unless other design conditions are specified in the Thermal Design Requirements, the product shall be designed to comply with the requirements of this standard under the following standard design conditions:

- Average heat output
- Most severe thermal environment conditions, including any additional constraints imposed under this standard
- Nominal supply voltage
- Sea level altitude

For products that can be configured with various options, that is, modules, drives, and so on, the product shall be designed to comply with the requirements of this standard under all possible configuration combinations.

For purposes of thermal design, the information contained under the following subheads shall apply.

4.4.1 Cleanliness

The product and its parts shall be assumed as free from dust and/or corrosion or any other build up of material on, or blockage of *thermally active* surfaces that would affect the heat transfer, unless specifically included as a special requirement. Examples of a special requirement include, lint or dust build up on heat sink fins or corrosion in water cooled systems.

4.4.2 Thermal Surroundings

The design thermal environment classification for stand-alone products or separately mounted products specifies the maximum and minimum environment temperatures, the range and the maximum rate of change, as well as its temperature, has influence on the thermal performance (temperatures) of components that make up the product. There is need, therefore, to define the condition of the environment surrounding the product. Refer to subhead 4.3.1.

For design purposes, the thermal environment surrounding the stand-alone product of the separately mounted product will be assumed to be as follows, unless specifically stated otherwise.

- **Convective environment -** The air surrounding the exterior of the product, with the exception of that air in the region surrounding the discharge grill(s), is at the environment temperature. The surrounding air is essentially still, except for:

  a. Nominal air currents that would be representative of that which would be found in a space in which the product would typically be used

  b. Air currents caused by the cooling air fans or blowers (if present) that are part of the product, and

  c. Air currents resulting from temperature induced natural convection at the exterior surface(s) of the product or from the vent grill(s) of the product.

  For products that are cooled by natural convection, the surrounding air is to be still except for air currents resulting from temperature induced natural convection at the exterior surface(s) of the product or from the vent grill(s) of the product.

- **Radiative environment -** Solid surfaces in the environment surrounding the product are assumed to have a total hemispherical emissivity typical of that which would be found surrounding the product when the product is in service.
- **Conductive environment -** Solid surfaces in direct contact with the product are assumed to be at the environment temperature.

4.4.3 Flow Paths

All flow paths for thermal control shall be assumed as fully open and externally unrestricted, unless specifically stated otherwise as a special requirement.

4.4.4 Altitude Correction

DEC STD 102-0 provides for a reduction in the maximum environment temperature of 1.8 °C/1000 meters (1.0 °F/1000 feet) for operation at high altitude sites. This adjustment accounts for the reduced air density at altitude and is to be applied, unless specifically stated otherwise.

4.5 THERMAL DESIGN DATA FOR EMBEDDED PRODUCTS

A design thermal environment classification is used during the design and development of products that are later repackaged (embedded) within other products.

This classification shall be subordinate to the design thermal limits of the embedded product when that embedded product is used as part of another product. Refer to subhead 4.2.

The design thermal environment classification for embedded products is to be used as a design aid and not a requirement for a product under design. For example, a quad module may have been designed for the following local environment classification:

- Maximum local ambient temperature 50 °C
- Minimum air flow velocity 200 linear feet per minute (LFM)
- Minimum air flow rate 10 cubic feet per minute (CFM)

However, this quad module may be used in any product, without regard to the local environment conditions, provided that no design or maximum thermal limits are exceeded when the product is operated to the extremes of its design thermal environment classification. Refer to subhead 4.1.

4.6 THERMAL OPERATING CONTROLS

Consideration shall be given to the use of thermal operating controls. If used, the thermal operating controls shall be stable and not result in any objectionable cyclic operation. The thermal operating control, if active, shall be separate from the thermal limit controls. Refer to subhead 4.7.

4.7 THERMAL LIMIT CONTROLS

Consideration shall be given to the use of thermal limit controls to prevent the maximum temperature limit of any component from being exceeded when the product is subjected to blockage, fan failure, or other upset conditions impeding the thermal control of the product. Such controls are sometimes required to meet DEC STD 119 (all sections).

4.8 THERMAL - ACOUSTIC INTERACTION

Elements of the thermal design, specifically fans and blowers, will impact the acoustic design of the product. Considerations shall be given to this during the thermal design process with the overall goal of achieving acceptable thermal control and reliability, while meeting the acoustic limits as described in *DEC STD 104-0 Product Acoustic Noise Acceptability*.

4.9 SUBSYSTEM THERMAL DESIGN DATA

Some products are designed to accept a variety of printed-circuit boards, drives, or other embedded products that are designed or purchased separately. For such products, the design specification shall include the information defined under subhead 4.3.2 or 4.3.3, for the space in question, so that embedded products can be designed separately for use in the product.

5 THERMAL DESIGN VERIFICATION TEST

5.1 GENERAL

All powered products sold by Digital shall undergo a thermal design verification test to demonstrate that the thermal design requirements under heading 4 have been met.

5.2 PURPOSE

The primary purpose of the thermal design verification test is to demonstrate that all components, units, and subassemblies that comprise the product will operate at temperatures equal to, or less than, their design thermal limits when the product is operated at the extremes of its design thermal environment classification.

5.3 TESTING LOCATION

Thermal design verification testing is often conducted in an open, temperature controlled laboratory at an ambient temperature of 20 to 25 °C. The test results are then adjusted to account for the design maximum environment temperature. This adjustment assumes that the heat transfer paths, both inside and outside of the equipment under test, can be modeled as a linear system, that is, the convective and radiative heat transfer coefficients do not vary with temperature. It can be shown that these coefficients are only weak functions of temperature in the typical range of interest, thus the stated assumptions are valid.

Alternately, thermal design verification testing can be conducted in an environmental chamber operated at the maximum environment temperature. This obviates the need to correct for the maximum environment temperature. However, since chambers typically have air circulation systems and are more confining, the need to assess the impact of the chamber effects is more critical than in the case where the test is conducted in an open, temperature controlled laboratory.

Conducting the thermal design verification test in a laboratory and extrapolating the data to the maximum environment temperature conditions has the advantage of convenience. Also, local air velocities exterior to the product under test generally will be low and reflect

actual in-service conditions. This reduces or eliminates the need for data adjustments for chamber effects.

Testing in an environmental chamber operating at the extreme of the design thermal environment classification, and where adjustments for the chamber effects have been made, results in maximum component temperatures during test. This allows the functional performance of the product at the maximum environment temperature to be assessed. It also allows the performance of thermal operating controls and thermal limit controls to be determined.

5.3.1 Test Environment

The thermal test environment has to be established so as to clearly simulate the in-use environment of the product under test; otherwise, the results of the thermal design verification test will be biased.

In a thermal test, the following three factors affect the temperature of components, units, and subassemblies that comprise the product:

- Environment air temperature surrounding or entering the product under test.
- Environment air motion over or adjacent to the product. This can influence exterior heat transfer coefficients and air flow through the product under test.
- Condition of environmental surfaces surrounding the product under test: temperature, emissivity, and proximity of equipment or surrounding surfaces.

In the thermal design verification of products that are free standing and must function in an environment with virtually still air, the last two items (collectively referred to as chamber effects) have the potential of biasing the test data and results. For example, consider a large, forced convection-cooled product under test in an environmental chamber. If the product air intake or exhaust is situated close to or up against the chamber intake or exhaust, the air flow through the product will be affected (either increased or decreased) and the thermal performance of the product will be skewed. For smaller products, employing either forced or natural convection cooling, chamber air flow can have significant impact on the thermal performance.

For natural convection-cooled products, anywhere from 10 to 60% of the thermal energy may leave the product by radiating to adjacent surfaces. If these adjacent surfaces are at other than ambient temperature or are reflective, the product thermal performance will be impacted. Therefore, in planning, setting up, and executing a thermal design verification test either in a laboratory or particularly in a chamber, the influence of these chamber effects has to be assessed. If this assessment shows that the environment air motion and/or the condition of adjacent environment surfaces will influence the test results, then corrective action to reduce the air motion and to more closely simulate the physical design environment shall be taken.

Finally, conduction is generally not used as a means of heat removal from the exterior surfaces of stand-alone products. Therefore, care must be taken in testing so as not to introduce conductive heat flow paths not intended in the design.

5.3.2 Test Conditions

Thermal design verification tests shall be conducted under the following test conditions:

- For products having various option combinations or configurations, a test shall be conducted for the worst case configuration where the worst case has been identified and documented. If no worst case configuration has been identified, preliminary tests shall be conducted to identify the worst case configuration.
- The product shall be functioning, running typical diagnostics or operating software, and operating at steady state.
- The orientation of the product, with respect to gravity, shall be the same as that intended for normal operation.
- The product shall be operating under nominal electrical supply voltage.
- There shall be minimum clearance envelope about the exterior of the product as described under subhead 4.2.
- Flow paths shall be externally unrestricted unless otherwise required per subhead 4.4.2.
- Thermal operating controls, if present, shall be adjusted to emulate operation at the maximum environment temperature. For example, in a system with variable fan speed control, set the fan voltage to its maximum value.

Further, the thermal design verification test for stand-alone products or separately mounted product shall be either conducted at the environment conditions listed below or conducted at other environment conditions and the results corrected to the following environment conditions:

- Air circulation shall be natural or as would be found in the normal operating environment of the product under test. Enhanced circulation will be allowed only if enhanced circulation is specifically set forth in the Thermal Design Requirements.

  Air temperature will be at the maximum environment temperature.
- Surrounding surfaces are to be at the maximum environment temperature and have thermal emissivities comparable to surfaces that would normally be surrounding the product when the product is in service.

5.4 COMPUTATION OF EXPECTED TEMPERATURES

Expected temperatures at average heat output shall be calculated from the test data by correcting for the difference between the maximum environment temperature and the ambient temperature during testing and, if necessary, correcting for the temperature difference between the measurement position on the component or device and the critical location where the limit applies.

For certain categories of components, adjustment for design heat output shall be made. This correction is made to account for the difference in temperature rise that would occur if the component in question were tested while it (the component) was dissipating heat at the design heat output rate.

5.4.1 Corrections to/for Maximum Environment Temperature

The maximum environment temperature shall be adjusted to account for the test site elevation above sea level. The test data shall then be corrected to this adjusted maximum environment temperature.

5.4.1.1 Altitude Adjustment to the Maximum Environment Temperature - The maximum environment temperature, specified at sea level shall be adjusted to account for the test site elevation above sea level. This adjustment is made by reducing the maximum environment temperature by the product of the test site elevation (measured in thousands of feet or thousands of meters) and the factor 1.8°C/1000 meters (1.0°F/1000 feet). Refer to subhead 4.3.

5.4.1.2 Correction for Maximum Environment Temperature - To correct test data to account for the difference between the maximum environment temperature and test ambient temperature, add this difference to the test data. This will yield the test temperatures that would be expected if the test were conducted at an ambient equal to the maximum environment temperature.

5.4.2 Correction to Limit Location

To correct for the temperature difference between the measurement position on the component and the critical location where the temperature limit applies, add the measurement location temperature to the product of the component nominal power and the thermal resistance between the measurement location and the critical location where the limit applies. This will yield the expected temperature at the limit location. These procedures are outlined in A-SP-EL-EN120-00, *Thermal Guidelines and Limits*.

5.4.3 Correction for Maximum Component Heat Output

The correction for the design component heat output, required for certain categories of components, shall be made as follows. Subhead 5.4.4 contains examples of these computations.

1. Operate the product with the component in question powered. Measure the component temperature(s) (Tc1), the ambient temperature (TA1), and the component heat output (Q1).
2. Operate the product with the component in question unpowered. Measure the component temperature(s) (Tc2), and the ambient temperature (TA2).
3. Account for any difference in ambient temperature between steps 1 and 2 above by subtracting the ambient temperature from step 2 from that of step 1 and adding this difference (including the sign) to the measured component temperature of step 2. This result will be referred to as the adjusted unpowered component temperature (Tc2a).

$$Tc2 = TA1 - TA2 + Tc2$$

4. Determine the component temperature rise resulting from its own power by subtracting the adjusted unpowered component temperature (Tc2a) from the powered component temperature (Tc1).
5. Determine the component temperature rise at the design heat output by multiplying the temperature rise calculated in step 4 by the ratio of the design component heat output divided by the measured component heat output.

6. Determine the component temperature at the design heat output and the measured ambient temperature, by adding the component temperature rise at the design heat output as computed in step 5 to the adjusted unpowered component temperature computed in step 3.

5.4.4 Example of Computations and Corrections

5.4.4.1 Corrections Applied to Integrated Circuits - Consider a system having a Class B environment classification (maximum environment temperature of 40°C). Within this system is a chip that has a junction design temperature limit of 110°C, a design heat output of 0.9 W, and a junction-to-heatsink thermal resistance of 16°C/W. During a test conducted at an ambient temperature of 23°C, the device heatsink was measured to be 75°C. Correct the measured data to account for the maximum environment temperature as follows:

$$Tmc = Tm + (Tme - Ta)$$

where

Tmc	=	Corrected temperature (adjusted for the maximum environment temperature)
Tm	=	Measured temperature
Ta	=	Test ambient temperature
Tme	=	Maximum environment temperature

then

$$Tmc = 75 + (40 - 23) = 92 \deg C$$

Correct the measured data (as adjusted above) to determine the temperature at the limit location (junction) as follows:

$$Tj = Tmc + \theta jc * Qdes$$

where

Tj	=	Junction temperature
θjc	=	Thermal resistance, junction to heatsink = 16°C/W
Qdes	=	Design component heat output = 0.9 W

then

$$Tj = 92 + 16 * 0.9 = 106.4 \deg C$$

The corrected junction temperature (106.4°C) is within the design temperature limit of 110°C.

5.4.4.2 Correction Applied to Drives - Consider another class "B" system that includes a disk drive. The purchase specification states that the design heat output for the drive is 28 W and the maximum HDA operating temperature (that is, maximum temperature limit) is 60°C. During a test with the full system powered and at an ambient of 20°C, the measured drive temperature and heat output were 38°C and 23 W respectively. In a subsequent test, with the drive unpowered and at an ambient of 22°C, the drive temperature was 32°C. Correct for the difference in test ambient temperature as follows:

$$Tc2a = Tc2 + (TA1 - TA2)$$

$$Tc2a = 32 + (20 - 22) = 30 \deg C$$

where

Tc2a	=	Unpowered drive temperature adjusted for the test ambient temperature during the powered drive test
Tc2	=	Unpowered drive temperature
TA1	=	Test ambient temperature during test with drive powered
TA2	=	Test ambient temperature during test with drive unpowered

Determine temperature rise of the drive above the unpowered drive temperature at the design heat output.

$$DT = (Tc1 - Tc2a) * QD/QM$$

$$DT = (38 - 30) * 28/23 = 9.7 \deg C$$

where

DT	=	Maximum powered temperature rise of the drive above the unpowered drive temperature
Tc1	=	Measured drive temperature with drive powered
QD	=	Design drive heat output
QM	=	Measured drive heat output

Determine the expected drive temperature at the drive design heat output and at the maximum environment temperature as follows:

$$TMM = TC2A + (Tme - TA1) + DT$$

$$TMM = 30 + (40 - 20) + 9.7 = 59.7 \deg C$$

where

TMM	=	Expected temperature at design heat output and maximum environment temperature
Tme	=	Maximum environment temperature

The resulting temperature (59.7°C) is within the maximum operating temperature limit of 60°C.

Further examples of the methods to use in calculating *expected temperatures* and making corrections may be found in EL-EN120-00.

5.5 COMPUTATION OF MAXIMUM OPERATING TEMPERATURE RANGE

In some instances a component or item will also have a limit on the maximum operating temperature range. To determine the expected temperature range that a component or item will see, subtract the minimum environment temperature from the expected temperature as calculated under subhead 5.4.

5.6 REPORT

A test report shall be issued to document the results and conclusions. The report shall contain the following information:

- Administrative data (date, location, contact person).
- A summary.
- Complete and explicit description of the product tested, including all options and accessories as well as serial numbers and revision levels.
- A completed copy of the Thermal Design Requirements section of the Engineering Design Specification/Purchase Specification document, as called for under subhead 4.2.
- Complete test description, including: time to reach steady state, specific software running, temperature sensor locations, type and accuracy, laboratory ambient conditions, and any other techniques or procedures used.
- Calculated data.
- Results - comparison of calculated data with limits and/or guidelines. Identify key location(s) to be monitored during DEC STD 102-1 testing and their respective design temperature limits.
- Sketches and/or photographs of test setup and equipment.
- Conclusions.
- All raw data including temperature, and power (volts, amperes) data.
- Sample calculations.
- Any MTBF evaluations and certifications, as required per subhead 5.8.

5.7 PASS/CONDITIONAL PASS/FAIL CRITERIA

The expected temperatures (the measured temperatures corrected per subhead 5.4) and the temperature range, if applicable, shall be compared with the design thermal limits.

The product will have satisfied the requirements of DEC STD 120-0 if:

- No design temperature limits are exceeded, and
- No design temperature range limits, if applicable, are exceeded.

The product will have conditionally satisfied the requirements of DEC STD 120-0 if:

- No more than 10% of the product IC population exceed their design temperature limits or their design temperature range limits, if applicable, by more than 4°C, and
- No maximum temperature limits or maximum temperature range limits, if applicable, for these components are exceeded, and
- No drive or other identified critical component exceeds its design temperature limits or design temperature range limits, if applicable.

The product will have failed the requirements of DEC STD 120-0 if:

- Any IC exceeds its design temperature limit or design temperature range limit, if applicable, by more than 4°C, or

- Any drive or other identified critical component exceeds its design temperature limit or design temperature range limit, if applicable, or
- Any component exceeds its maximum temperature limit or maximum temperature range limit, if applicable.

5.8 FAILED THERMAL DESIGN VERIFICATION TEST REQUIREMENTS

A *failed* thermal design verification test will require one of the following actions:

- Change or modification to the Thermal Design Requirements
- Redesign of the product
- A waiver

If the design thermal limits as specified in the Thermal Design Requirements are changed by the responsible engineer to achieve a pass or conditional pass, a certification documenting the basis of the change is required as an attachment to the test report. This certification shall address the impact of the design thermal limit reset on product reliability.

If the product is redesigned, it is required that the thermal design verification test be rerun.

6 COMPONENT THERMAL LIMITS

It is the responsibility of the responsible engineer to establish, define, and document the Thermal Design Requirements for the product in accordance with the requirements under subhead 4.2 of this standard. This entails specifying the maximum temperature limits and the design temperature limits for components, subassemblies and units comprising the product.

The maximum temperature limits are temperatures that shall not be exceeded. The design temperature limits are temperatures to which the system is designed.

The design temperature limits established here can be viewed as starting points for the design. Limits are provided in EL-EN120-00, which have been used successfully in the past. It is recognized, however, that strict adherence to the guidelines can result in designs that may be thermally conservative and restrictive. A mechanism is, therefore, provided to establish design temperature limits that are higher than those recommended by the guidelines. It is advised that this latter approach be used cautiously and done on a firm, technical basis including an evaluation of the impact of the higher temperature on product reliability. Refer to subhead 7.1.2.

6.1 MAXIMUM TEMPERATURE LIMITS

The maximum temperature limit is the highest operating temperature at which a component, subassembly, or unit is warranted or guaranteed by the manufacturer of the item.

This temperature, which refers to a temperature at a specific location on or in the item and not to an ambient or environment temperature, is to be obtained from the manufacturer's specifications. Reference to this source shall be included in the Thermal Design Requirements section of the product specification. Refer to subhead 4.2.

If the manufacturer's data appears questionable, that is, too low or too high, it is important to inquire as to the basis of the questionable data. This is particularly important when the item in question is to be operated at or close to its maximum temperature limit.

6.2 DESIGN TEMPERATURE LIMITS

The design temperature limit is the highest temperature that a subassembly or unit will be allowed to operate when functioning in a powered system. This temperature, which refers to a temperature at a specific location on or in the item in question, shall be established by using either EL-EN120-00 where applicable, or temperature versus reliability data. If, and only if, neither the guidelines apply nor temperature versus reliability data is available, then a design temperature limit for use as a starting point in the thermal design can be calculated using maximum temperature limit information.

6.2.1 Design Temperature Limits Using Guidelines

The design temperature limits contained in EL-EN120-00 may be adopted as the design temperature limits for all components, subassemblies, and units to which the thermal guidelines apply. There are instances where increased product reliability goals are to be achieved. In this situation, as well as others, setting design temperature limits that are lower than those resulting from the adoption of the thermal guidelines may be appropriate.

Use of the thermal guidelines to establish the design temperature limits or the selection of design temperature limits that are lower than the guideline values require no additional documentation to be added to the Thermal Design Requirements section of the product specification. Refer to subhead 4.2. Note, however, that the setting of lower limits for embedded products will result in larger thermal control means at the cabinet level.

6.2.2 Design Temperature Limits from Temperature Versus Reliability Data

Temperature versus reliability data may be used to establish design temperature limits for components or subassemblies.

In such instances, either a summary of, or a reference to, the temperature versus reliability data shall be included in the Thermal Design Requirements section of the product specification.

6.2.3 Design Temperature Limits from Maximum Temperature Limits

A design temperature limit for components can be calculated from a maximum temperature limit if and only if the thermal guidelines of EL-EN120-00 do not apply and if temperature versus reliability data is not available. The resulting design temperature limit is to be used cautiously and effort is to be made to substantiate the value.

The calculated design temperature limit is determined using an assumed environment temperature of 32°C (Class A per DEC STD 102-1) regardless of the environmental classification of the system.

To calculate the design temperature limit, multiply the temperature difference between the maximum temperature limit and 32°C by the factor 0.75, then add this to the assumed environment temperature (32°C). For example, given a maximum temperature limit (MTL) of 150°C, the design temperature limit (DTL) is calculated as follows:

$$DTL = 32 + 0.75 * (MTL - 32)$$

$$= 32 + 0.75 * 118$$

$$= 120.5 \deg C$$

For components whose design temperature limits are established from the maximum temperature limits, reference to the specific source of the maximum temperature limit data shall be included in the Thermal Design Requirements section of the product specification. Refer to subhead 4.2.

6.3 DESIGN TEMPERATURE RANGE LIMITS

The design temperature range limit is the temperature range that a component, subassembly, or unit will be allowed to operate over when functioning in a powered product. This temperature range refers to a temperature at a specific location on or in the item in question. This range shall be established for, and only for, those components, devices, subassemblies and units whose operation is affected by operating temperature range.

6.4 RATE OF CHANGE OF TEMPERATURE LIMIT

The rate of change of temperature limit is the maximum temperature change per unit of time that a component, device, subassembly, or unit will be allowed when functioning in a powered product. This rate of change limit, which refers to a temperature on or in the item in question, shall be established for, and only for, those items whose operation is affected by the rate of temperature change.

7 THERMAL DESIGN PRACTICES

Competent thermal design engineering of powered products under development will reduce design cycle time and improve product reliability. Thermal design is a process that involves the following steps:

1. Establishment of specific design thermal limits for the components, subassemblies, and units that comprise the product
2. Development of a thermal design strategy to achieve a design that is consistent with these thermal limits
3. Analysis and experimentation to identify and quantify specific features that impact the thermal design
4. Design verification testing of the final design to demonstrate that the design thermal limit requirements have been met
5. Documentation of the thermal design requirements, strategy, analysis/experimentation work, and design verification test results

Establishing design thermal limits (step 1) and the design verification testing (step 4) are requirements of this standard and are fully discussed under headings 4, 5, and 6. The development of a thermal design strategy (step 2) is also a requirement of this standard. Further comments on strategy are given under subhead 7.1.

The analysis and experimentation of step 3 and much of the documentation of step 5 are not requirements of this standard. They are, however, integral parts of the thermal design process; therefore, additional comment is given under subheads 7.2 and 7.3.

7.1 THERMAL DESIGN STRATEGY

Early in the product design process, there is a need to establish and communicate a thermal design strategy. This strategy will define how the product will be cooled, identify those components and subassemblies that will require the most attention, and establish the complexity of the thermal design task. In defining the thermal design strategy, consideration has to be given not only to the thermal requirements, but also to other product constraints such as cost, MTBF, package size, appearance, safety, and acoustic limits.

As an example, the thermal design strategy for a typical air cooled product would have to consider the following:

- Cooling mode: forced or natural convection
- Cooling requirements: component power dissipation
- Product reliability goals
- Volumetric and linear air flow rates
- Flow direction: front to back, side to side, bottom to top
- Component placement
- Grill size and placement
- Fan size and placement (forced convection systems)
- Internal air flow paths and resistances
- Dimensions
- Intended use

The thermal design strategy can have significant impact on the product design. As a result, considerations that define the strategy have to be investigated thoroughly. Following this, there is a need to communicate the strategy, along with an assessment of risks, to others involved in the product design. This communication can be done orally or in the form of a written report. It is recommended that the latter approach be taken to avoid errors in communication, which could impact the design and cycle time.

7.1.1 Component Heat Output

The most important piece of information required when establishing the thermal design strategy is the heat output for each element comprising the product. Without accurate data or with no data, the design is at significant risk. Under-estimation of heat outputs may result in a design that does not meet thermal limits and that requires extensive and expensive changes late in the design cycle. Over-estimation of heat dissipations may result in a design that is larger, noisier, and more expensive than competing products.

Heat output data generally comes from power requirements as identified by the electrical design engineer. There are a number of different power values for components. Some components have specified maximum, typical, and minimum values that apply if all the functionality of the device is used. Some components have different power requirements for different types of activities, such as start-up, idling, and read/write. In most, if not all cases, the specified powers are different from the power levels actually measured. There are occasions where the electrical design engineer includes a safety factor in his specification or power requirements so that the power supply will have some excess capacity.

Needless to say, the thermal design engineer must sort through this power data and select relevant and consistent design heat output values.

7.1.2 Thermal Related Reliability

The thermal reliability goal for the product is a factor that will influence the thermal design strategy and the selection of design temperature limits.

Since component MTBF and thus product MTBF are functions of the component temperature, products requiring greater MTBF should have lower design temperature limits than products where a lower MTBF is acceptable.

A thermal design that results in all components operating at or below their design thermal limits is not, however, necessarily the best overall design. It is quite possible that thermal control can be tightened for some components, while loosened for others to achieve acceptable, and yet competitive, design. Thus, the design thermal limits (temperature, range, and rate of change) may be reset in order to pass the thermal design verification test if it can be shown that the impact on the product reliability goal will be acceptable. However, the maximum thermal limits (temperature, range, and rate of change), as identified under subhead 4.2, shall not be exceeded without a specific waiver, as stated under subhead 2.2.2, even though the product reliability goal will not be exceeded.

7.2 ANALYSIS AND EXPERIMENTATION

As the product design is developed, thermal control features, such as air flow rate, grill area, heat sink size, and so on, are established by analytical and/or experimental techniques. The most secure product design is one that has agreement between analysis and test. This agreement indicates that the mechanisms of thermal transport are understood by the design team and that appropriate design features have been incorporated into the product.

Many different techniques are available to establish the basis for thermal control features.

Although strongly recommended as a continuing part of the product design and development process, analysis and experimentation are not requirements of this standard.

7.3 DOCUMENTATION OF PRODUCT THERMAL DATA

Thermal data is required by the design team, early in the design process, and by the customer (field service) prior to installation.

The needs of the customer are addressed in DEC STD 009-1. The data required by DEC STD 009-1 is extracted from the final engineering tests and product design documentation. Its purpose is to provide Digital's customers with accurate and consistent thermal data for the products purchased, so that space, airflow, and facility cooling capacity be prepared in advance of delivery and installation.

DEC STD 120-0 addresses the need of the product design team to identify the thermal design requirements and to assess the extent to which the product design meets these requirements. Also, since this data is considered proprietary, it is quite appropriate to document it separately from DEC STD 009-1.

```
PRODUCT REQUIREMENTS DOCUMENT OR PROJECT DESIGN SPECIFICATION

        _____ Thermal Design Requirements

1.      Thermal Environmental Classification

        Class:  A ___, B ___, C ___, Altitude Range ___ to ___ ft (m)

2.      Duty Cycle

        ____________________________________________________

3.      Environmental Air Quality

        ____________________________________________________

        ____________________________________________________

4.      Special Requirements

        ____________________________________________________

        ____________________________________________________
```

Although not required by this standard, the following documentation is recommended:

- A written description of the thermal design strategy.
- Reports or memos stating the requirements for specific control features (air flow, grill area, heat sink area, and so on) and the analytical/experimental basis for these features.
- Prototype test result reports.
- A final report indicating the initial design goals, trade-offs, and final design status. This report should also provide a summary of the thermal design process, including design alternatives examined and used, as well as those examined and discarded and, if available, a comparison of the actual performance versus the calculated performance.

7.4 PURCHASING OR ENGINEERING SPECIFICATION DATA FORMAT

7.4.1 Data Format

For components, modules, or subassemblies that are not stand-alone products, follow the format below for the presentation of thermal and related data:

_____THERMAL DATA

_____HEAT OUTPUT TABLE (WATTS)

At idle (if this condition exists)

	Minimum	Maximum
	_____	_____

Fully Operational

	Minimum	Maximum
	_____	_____

Notes:

1. Indicate heat outputs at minimum and maximum supply voltages respectively.
2. If supply voltage may vary (that is, dc fans), provide above data for three voltages covering the range of operation.

_____MAXIMUM TEMPERATURE LIMIT(S) (specify point or points on component)

Location	Temperature °C
_____	_____
_____	_____
_____	_____

____MINIMUM TEMPERATURE LIMIT(S) (specify point or points on component)

Location	Temperature °C
_____	_____
_____	_____
_____	_____

_____ COOLING APPROACH

_____ Natural Convection, _____ Forced Convection,

_____ Radiation, _____ Conduction

_____ MAXIMUM OPERATING TEMPERATURE RANGE(s)

Location	Temperature Range °C
_____	_____
_____	_____
_____	_____

_____ MAXIMUM ALLOWABLE TEMPERATURE RATE OF TEMPERATURE CHANGE

Location	Maximum Rate °C/Hour
_____	_____
_____	_____

_____ ALTITUDE RANGE _____ to _____ ft (m)

_____ AIR QUALITY

If air cooled, minimum air quality required for direct cooling

_____

_____

Note that reliability data required elsewhere in this specification is to include consideration for the stated air quality, if appropriate.

_____ THERMAL CONTROLS OR LIMITS

Location	Set Point	Range

_____

_____ SPECIAL REQUIREMENTS

_____

_____

Indicate N/A for any data request that does not apply.

For assistance in obtaining the proper data, verifying that the data is appropriate, or completing this data set, contact the Thermal Engineering Group.

_____ LOCAL ENVIRONMENT DESIGN CONDITIONS

	Maximum	Minimum
Temperature	_____	_____
Humidity	_____	_____

_____

_____

Provide local environment data only if the item to be designed is being considered under subhead 7.1 and can be tested according to DEC STD 102-1, subhead 2.1.4.

7.4.2 Coordination

It is recommended that those responsible for preparing or reviewing thermal data for a component to be purchased also review this data with systems engineers responsible for using these components within systems, to ensure that components under consideration will meet the thermal requirements of the system.

7.5 MANAGEMENT CHECKLIST

Product development managers may find the following checklist useful when they would like to emphasize a commitment to a sound thermal design during their product development.

- Thermal expertise linked and involved from product inception phase onward.
- For buy-outs, thermal expertise assists in candidate product screening, specification development, and as required, with vendor interface.
- Product team commits early on (Phase 0 and Phase 1) to DEC STD 120-0 design thermal limits.
- Thermal design approach (not just intent) to achieve commitment early in product development.
- Funding for thermal design is in the development budget. Qualification testing, which comes at the end of the design, is also necessary, but not the same.
- Thermal expertise is present at appropriate hardware design team meetings.
- Periodic quantitative thermal status against commitment is made visible at higher level project reviews.

APPENDIX A REFERENCED DOCUMENTS

A.1 EL-Class Digital Documents

EL-Class Number	Document Title
EL-00009-01	*DEC STD 009-1 Product Engineering Specifications: Electrical, Physical, and Environmental Parameters*
EL-00009-02	*DEC STD 009-2 Product Engineering Specifications: Requirements for Specifying Reliability Parameters*
EL-00066-02	*DEC STD 066-2 Waivers to Digital Design Standards*
EL-00102-00	*DEC STD 102-0 Environmental Standard for Computers and Peripherals - General Test Requirements*
EL-00102-01	*DEC STD 102-1 Environmental Standard for Computers and Peripherals - Temperature, Humidity, and Altitude Test Requirements*
EL-00104-00	*DEC STD 104-0 Product Acoustic Noise Limits*
EL-00119-00	*DEC STD 119-0 Digital Product Safety - Introduction and General Requirements*
EL-00119-01	*DEC STD 119-1 Digital Product Safety - Design Criteria*
EL-00119-02	*DEC STD 119-2 Digital Product Safety - Test Procedures*
EL-00119-03	*DEC STD 119-3 DIGITAL Product Safety as C100 Requirements*
EL-EN120-00	*Thermal Guidelines, Limits and Data*

Use VTX SMC to order copies of EL-class documents from Standards and Methods Control. Send distribution questions to JOKUR::SMC or call DTN: 234-4423.

```
+---------------------------------------------------------------------+
|                          READER COMMENTS                            |
|                                                                     |
| Your  comments  and suggestions  will help  Standards and Methods   |
| Control improve their services and documents.                       |
+---------------------------------------------------------------------+
```

Did you request this document? _____ If so, did it arrive within a satisfactory period of time? _____ Please comment.

What are your impressions of this document? Consider format, organization, completeness, readability, and illustrations.

————————————**FOLD ON THIS LINE**———————————————————————— -

Did you find technical or clerical errors in this document? If so, please specify the page number(s) and the error(s).

Are the instructions for the update package clear? _____
Was an index available? _____ If not, is one needed? _____
Do you have other suggestions for improving this document?

The following information is optional:

Name _____ Mailstop _____

Department _____ Node _____

Send your comments to JOKUR::PROJECTS, or fold, staple, and send this page through interoffice mail to:

```
+------------------------------+
|       READERS' COMMENTS      |
| STANDARDS AND METHODS CONTROL |
|          NRO4/D4             |
+------------------------------+
```